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ORGANIC LIGHT EMITTING DEVICES AND MATERIALS INTEGRATED WITH ACTIVE MATRIX BACKPLANES FOR FLEXIBLE DISPLAYS

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ABSTRACT

The following paper details the development of a new phosphorescent emitting dopant molecule for organic light emitting diodes (OLEDs). A systematic series of heteroleptic tris-cyclometallated iridium compounds were fabricated. Of the molecules, the fac-Ir(dfppy)(dfppz)2 compound had the blue-est emission with the highest quantum efficiency. Phosphorescent emitting OLEDs (PhOLED) were fabricated and properties measured. The emitting dopant was integrated into a device structure and the properties measured as a function of doping concentration. The device efficiency is 20 lm/W at 100 'cd/m^2 and a peak emission of 498 nm. The Army's Flexible Display Center (FDC) has fabricated thin film transistors on a rigid opaque substrate that make up an active matrix (AM) backplane. ARL's OLEDs are being integrated with the AM backplanes to demonstrate high performance emissive test demonstrator displays with a 1.1" diag.

1. INTRODUCTION

The Army is developing flexible displays through the Flexible Display Center (FDC) at Arizona State University to support the Army's transformation to a network-centric battle field. Flexible displays offer rugged, low power, novel form factors, and day/night readability technology that exceed the performance of current glass based liquid crystal displays. In FY07, the FDC is transitioning the first generation 4" diagonal reflective displays to the Future Force Warrior and PEO Soldier. The rapid technology transition is enabled by the unique university-government-industry partnership model. The FDC partnership is divided into critical technology elements that includes; materials companies, electro-optic device and display companies, tool manufactures, and military integrators. The FDC is integrating the critical intellectual property (IP) from these partners into flexible display form factors. This paper illustrates how this model works. ARL both manages the FDC and is a technology partner with the FDC. ARL has developed several novel class of organic materials for electro-optic applications.

Fig. 1 Flexible Display Center Partnership Model

This paper details the heteroleptic tris-cyclometallated iridium compounds and the integration of devices based on these compounds with active matrix backplanes from the FDC.

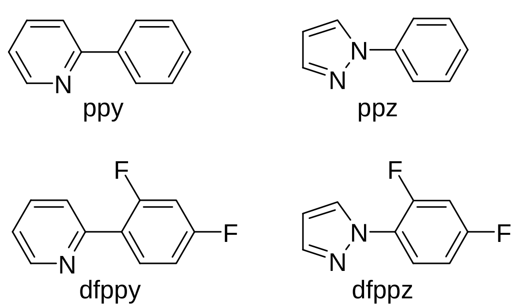
Recently, there has been growing interest in the use of cyclometallated iridium (III) complexes in a variety of applications such as oxygen sensing,[1] biological labeling[2] and in particular, as phosphors in organic light emitting diodes (OLEDs).[3] Large improvements in OLED efficiencies have been realized by incorporating triplet state emitters such as *fac*-Ir(ppy)$_3$ (ppy = 2-phenylpyridine) as dopants in the emissive layer.[4,5] Iridium cyclometallates often possess favorable photo-properties for OLEDs including short phosphorescent lifetimes, high quantum efficiencies and good stability. The emission color can be readily tuned from blue/green to red by judicious modification of the coordinated ligands, however, there are fewer reports of blue emission from these species.[6-8]

A component of the Army's Flexible Display Center is the demonstration of emissive high performance active matrix displays on flexible substrates. The FDC is simultaneously developing reflective displays on flexible substrates. The active matrix backplane development is same for the reflective and emissive technologies, where the different display technologies require different pixel designs. The FDC has the parallel mission to demonstrate pilot-scale manufacturability of these displays. The FDC roadmap starts with low-resolution test demonstrators to rapidly develop the integration technology for the displays. The displays detailed this paper are test demonstrators with a resolution of 64x64 pixels in a 1.1 diagonal inch (1.1" diag.).

2. ORGANIC MATERIALS AND DEVICES

A systematic series of heteroleptic tris-cyclometallated iridium compounds were designed and synthesized. [9] The meridional isomers of complexes were first prepared using a variation of a previously reported technique. [1]

In order to design efficient blue phosphors, it is critical to understand the structure-photophysical property relationship. To this end, several heteroleptic tris-cyclometallated iridium compounds were prepared with systematic changes in their ligand systems. The mixed cyclometallates are comprised of the ligands 2-phenylpyridine, 1-phenylpyrazole (ppz) and two fluorinated derivatives, as shown in Fig. 2. At the bottom of Fig. 2, the new complexes **3 – 8**, along with the previously reported homoleptic compounds **1**, **2**, **9** and **10**,[9] form 3 homologous series, two of which feature pyridine replacement by pyrazole: **1** → **3** → **5** → **9** (non-fluorinated) and **2** → **4** → **8** → **10** (fully fluorinated). A third series, of the (pyridyl)(pyrazolyl)$_2$ group, **5** → **6** → **7** → **8**, is characterized by increasing fluorination, where difluorophenyl is attached first to the pyridyl ligand, then to the pyrazolyl ligands and finally to all three.



1 Ir(ppy)$_3$	**3** Ir(ppy)$_2$(ppz)	**5** Ir(ppy)(ppz)$_2$	**9** Ir(ppz)$_3$
2 Ir(dfppy)$_3$	**4** Ir(dfppy)$_2$(dfppz)	**6** Ir(dfppy)(ppz)$_2$	**10** Ir(dfppz)$_3$
		7 Ir(ppy)(dfppz)$_2$	
		8 Ir(dfppy)(dfppz)$_2$	

Fig. 2. Ligand Structures and Formula of Tris-Cyclometallated Complexes

The following paper focuses on the facial isomers of these octahedral complexes since these molecules are much more photo-stable and emissive than the meridional isomers and are of greater interest to OLEDs. Complexes containing at least one pyridine ring are emissive at room temperature and each replacement of pyridine by pyrazole results in the emission maxima to blue shift by several nm. The highest energy emission in this group occurs at 460 nm for fac-Ir(dfppy)(dfppz)2. The quantum yields of the molecules 1 – 8 in Fig. 2 as measured in solution ranged from 0.27 to 0.77.

Based on the photophysical results, the molecule 5, Ir(ppy)(ppz)2 was fabricated in a full device structure, as illustrated in Fig. 3. The fac-Ir(dfppy)(dfppz)2 molecules have a more blue emission than the Ir(ppy)(ppz)2, which has a peak emission of 498nm. To date, organic molecules that can be host materials with an energy gap greater than 460nm have not been reported. The devices were fabricated in a multi-source thermal deposition tool on ITO coated glass substrates. The organic layers were deposited by sublimation from a metal boat. The emitting zone was a co-deposition of Ir(ppy)(ppz)2 molecules with a host molecule. Fig. 4 is the electroluminescent efficiency as a function of current density plotted against the luminance.

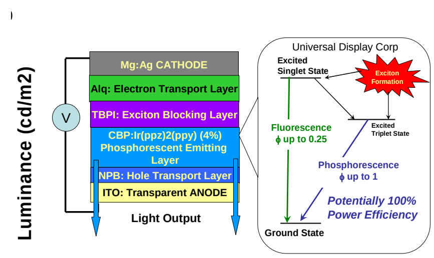


Fig. 3 Illustration of an phosphorescent OLED

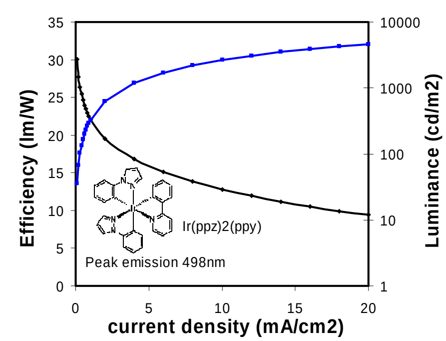


Fig. 4 Electroluminescence and current-luminance curves for phosphorescent OLED doped with Ir(ppy)(ppz)2

3. ACTIVE MATRIX BACKPLANE

The FDC has successfully implemented a 6" wafer scale pilot line for flexible displays. The first full display manufacturing flow is based on a channel passivated amorphous silicon thin film transistor (TFT) process. The a-Si based TFTs are fabricated at 180C to be compatible low-process temperature plastic substrates. The silicon is deposited with an FDC designed PEVD process. For OLEDs, the individual pixels are driven by a two TFT design. The 6" wafer pilot line will enable display up to 4" diagonals. For rapid display integration development, (4) test demonstrator backplanes are fabricated on one 6" wafer. (2) OLED designs and (2) reflective display designs as shown in Fig. 5. The FDC baseline process (as of September 2006) produces TFT arrays with statistically averaged μ_{sat} on the order of 0.45 $cm^2/V\text{-}s$. Fig. 6 is a photograph of the OLED pixel. The large pad is the OLED anode. The small patterned region is the TFTs the control the voltage at the OLED anode to turn the pixel on or off, with gray scale. Fig. 7 is a typical current voltage curve for a TFT fabricated at 180C on the FDC pilot line.

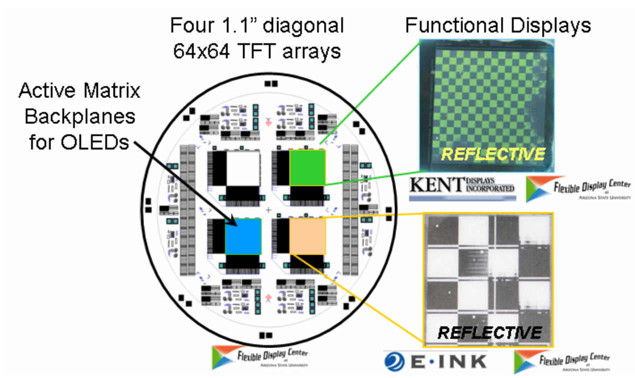


Fig. 5 Illustration of the FDC (4) test demonstrators fabricated on the 6" wafer pilot line.

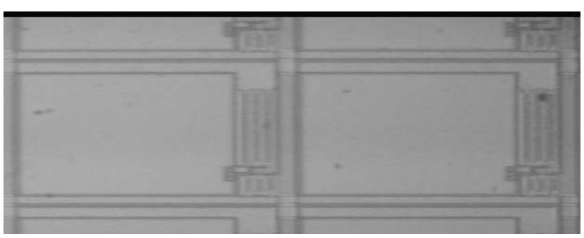


Fig. 6 Photograph of an OLED pixel fabricated from the FDC pilot line

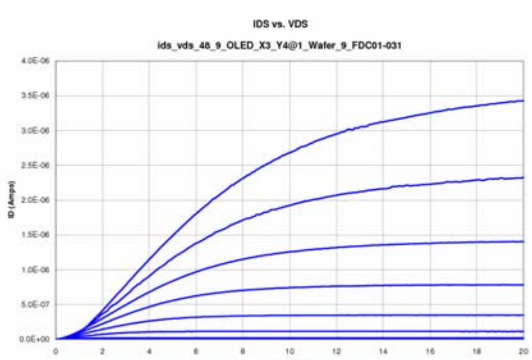


Fig. 7 Typical current-voltage curve for an FDC TFT

CONCLUSION

The Army's Flexible Display Center has made rapid progress towards the development of flexible displays for the soldier and vehicles. The industry, university, and government partnerships work together to enable the deliverables for the Army. The FDC and partners are developing two classes of display technologies. The first technology is based on reflective electro-optic pixel elements; EINK's electrophoretic technology and Kent Displays cholesteric liquid crystal technology. The second flexible display technology is based on emissive organic light emitting device (OLED) pixel elements with materials and devices developed by Universal Display Corp (UDC) and ARL. These partners are working with the FDC to integrate the full displays for Army applications.

ARL has developed a phosphorescent emitting dopant for emissive OLED based flexible displays. ARL is integrating the OLEDs with active matrix backplanes from the Army's Flexible Display Center. These new displays will offer unprecedented performance for information electronics in the network-centric battlefield. These rapid advances have been enabled by the unique FDC partnership model.

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